THE DEVICE FOR ULTRASONIC TREATMENT OF ALUMINUM AND MAGNESIUM MELTS

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Abstract – The paper considers the device for ultrasonic treatment of aluminum and magnesium melts. Also considers the stabilization methods of acoustic power transferred to the melt in the system with magnetostrictive transducer with feedback.

Keywords - ultrasonic technology, melt treatment, amplitude stabilization

I. INTRODUCTION

Application of a powerful ultrasonic treatment of the melt on the stage of technological metallurgy processing is increasingly being used through the last decade. Ultrasonic treatment of metal melts allows simultaneous realization of a number of technological processes, such as grain cleaning, segregation and degassing control, which gives a certain universality and effectiveness of this method when solving the problem of improving the quality of foundry products. Ultrasonic treatment of aluminum melts is the most effective, cheap and environmentally friendly mean of degassing dissolved hydrogen in Al-Si casting alloys.

II. TECHNOLOGICAL PROCESSING OF MELT

Natural degassing of liquid aluminum takes fairly long time (up to 1 hour), the hydrogen content is reduced to $(1 \div 2) \cdot 10^{-6}$ m^3 / kg. Such a long process of degassing is unacceptable in foundry production. Application of a short-term ultrasonic treatment of the aluminum melt (up to 2 min) allows to reduce the hydrogen content to $(0.7 \div 0.8) \cdot 10^{-6}$ m^3 / kg, which is acceptable for industrial application of this method [1].

High intensity of the melt degassing in aluminum alloys is achieved by high-energy ultrasonic treatment, when developed cavitation takes place. Cavitation in a liquid metal can be initiated by introducing a certain level of acoustic energy. The threshold of cavitation in typical aluminum melts is from 0.55 to 0.85 MPa, which is achieved at a radiation intensity of 10 W / cm^2 [2].

Currently, the following variants of technological processes have been applied (Fig. 1) using ultrasonic effects on low-melting-point fusible metal and their alloys:

I. ultrasonic degassing in a limited volume of melt with periodic or continuous feeding of the melt;

II. ultrasonic treatment of the melt during crystallization by the method of continuous casting of ingots or the exact casting of shaped castings [3].

One of the promising directions in solving the problem of improving the performance of aluminum alloys is the application of ultrasound to obtain a molten dispersion-strengthened composite materials and alloyed alloys [4].

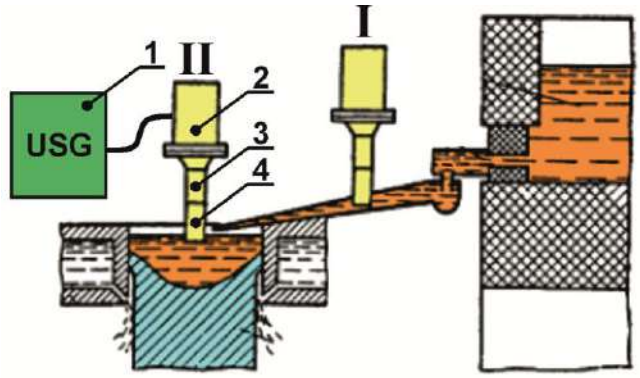


Fig. 1. Block diagram of the technological line of melt ultrasonic processing:
1 – ultrasonic generator, USGC-5-22 MS;
2 – magnetostrictive transducer with acoustic feedback MST-4-18 FB;
3 – middle sonotrode;
4 – niobium (titanium) emitter.

In addition, the influence of ultrasound in the mode of developed cavitation on crystallizing metal drastically changes kinetics of the crystallization process and gives an opportunity to get limit degree of grinding cast grain. (when its size is commensurate with the magnitude of the cross section of the dendrite branches of the second order). Ingots and shaped castings of aluminum alloys with no dendrite structure and with ultrafine particles of the secondary phases have a higher density and plasticity in the cast state and in homogenized state without strength reduction, besides, they have enhanced ability to plastic deformation and increased resource characteristics [2].

III. THE DEVICE FOR MELT TREATMENT

The «RELTEC» company has developed a device for ultrasonic treatment of aluminum and magnesium alloys (Fig. 2). This device is a part of the technological line for the preparation of aluminum and magnesium melts for casting into molds. Ultrasonic treatment of a limited volume of melt is carried out in an intermediate graphite crucible, into which molten metal is fed by a portion of 4-6 kg from resistance furnace for aluminum. The melt treatment in the crucible is carried out by the immersed ultrasonic transducer for 2 minutes.

The device for ultrasonic treatment of aluminum and magnesium melts includes an ultrasonic electric generator (USG), a magnetostrictive transducer (MT), an immersion radiating sonotrode (emitter), a control and stabilization system of oscillations of the emitter (CS).

Fig. 2. The device for ultrasonic treatment of aluminum and magnesium melts.

The best technological effect is achieved when the generator-transformer-sonotrode system is operated near their electrical and mechanical resonance. The reconciliation of the MT and the transducer must ensure an efficient transfer of mechanical vibrations through the contact area with the liquid metal. For transferring ultrasonic vibrations to a liquid metal, the sonotrode must be made of a material resistant to aluminum and magnesium melts. The most resistant to such influences are niobium alloys [2].

The control system is assembled in a computer rack and is executed on the basis of an industrial controller. On the front panel there is a computer monitor screen, through which interface of information-control system (operator panel) is implemented. Software, executed on the basis of industrial controller, forms the required structure of the control system (CS) rack. The software has three-level structure, the lower level is the USG software, at the middle level, all levels of software are interfacing, at the top level, a man-machine interface for monitoring and controlling is provided.

Stabilization of the regulation and the zero-to peak displacement amplitude of the sonotrode is provided by a feedback sensor installed in a magnetostrictive transducer (Fig. 3). The design of MT allows water cooling of magnetic circuits and windings. The ultrasonic electric generator supplies power to the MT with high-frequency currents (18-22 kHz), and also forms the polarization current of the working magnetic circuit, proportional to the displacement amplitude of the end face of the sonotrode.

Fig. 3. Magnetostrictive transducer construction with feedback (MST-4-18 FB).

IV. SHIFT AMPLITUDE STABILIZATION OF SONOTRODE END

The specific acoustic energy is characterized by the intensity of ultrasonic vibration, which can be expressed by the following function:

$$I = f(A), \tag{1}$$

where $A = f(P)$ – medium particles oscillation amplitude (shift amplitude stabilization of sonotrode end);
P – active electric power consumed by the magnetostrictive transducer.

To regulate and stabilize the acoustic energy of the ultrasonic device, developed by the “RELTEC” Co. , the dependence between acoustic energy (magnitude) and shift amplitude of sonotrode end is used. The device consists of control object and control device. The control object is an acoustic system based on ultrasonic magnetostrictive transducer with a feedback probe (FB). The control device is constructed on the basis of industrial sequence controller and computer. The controller software requires the specific control device structure. Fig. 4 demonstrates the block diagram of servo-system.

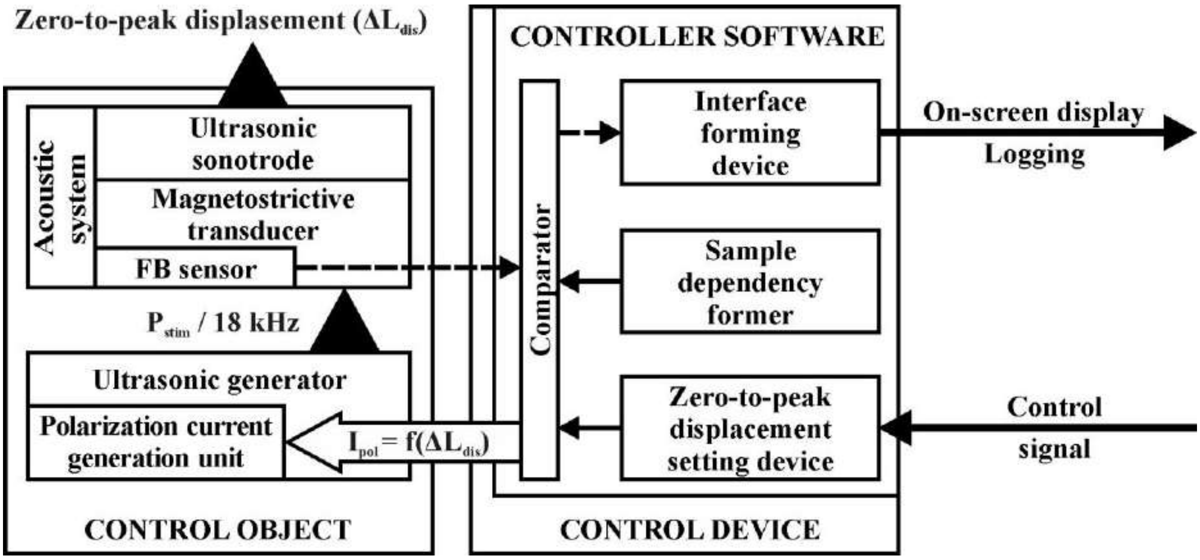


Fig. 4. The block diagram of the servo-system.

The developed method of ultrasonic attack (by means of the ultrasonic vibrations of the sonotrode working end) on the liquid or solid materials (product) has made it possible to develop new apparatus. The operating principle of this apparatus is based on the use of dependence between shift amplitude of the sonotrode working end of the acoustic system and system excitation power which is produced by the ultrasonic generator. Excitation power depends on the polarization current flowing through the magnetostrictive transducer winding, which is the load of the generator. The polarization current (I_{pol}) is formed by generation unit, which is built into the generator, and can be verified by the control signal (Fig. 4). When the polarization current is changed (for example, increases), the active electrical resistance (magnetostrictive transducer at its resonant frequency) decreases therefore the output power of the ultrasonic generator and shift amplitude increase (excitation power of the acoustic system) [5].

The load of the ultrasonic generator is the ultrasonic MST-4-18 FB magnetostrictive transducer (analogue MST-15A-18) with a feedback sensor, which is an active element of the ultrasonic acoustic system. The feedback sensor (FB) generates a feedback voltage proportional to shift amplitude of the transducer end, and to the shift amplitude of the sonotrode working end, the last is free sonotrode end connected to the magnetostrictive converter. “Sample” dependence, formed in the control device, is an analog of the practically established dependence $U_{FB} = f(\Delta L_{dis})$ of the MST-4-18 FB. The difference between the sample and current values of U_{FB} forms a control action on the polarization current unit. The goal is to reduce this difference to zero, which corresponds to the set value of the shift amplitude. Shift amplitude of the sonotrode working end is set by the operator, the set value is supported by positioning system, which is part of the data management system of the device.

In the considered ultrasonic device a rod magnetostrictive transducer equipped with an additional winding for acoustic feedback coupling is used. Feedback gives an opportunity to control shift amplitude of the sonotrode working end. However, liquid materials treatment is usually processed by membrane magnetostrictive transducers that are not equipped with feedback sensors. This converter like MST-2.5-22 (analogous to MST-6-22) was developed by RELTEC Co. and was successfully implemented in the technological lines. When using this converter in the system of regulation and stabilization of acoustic energy, a simplified functional relationship between the melt-driving acoustic power and the electrical power consumed by the converter is used:

$$P_{acoustic} = f\,(P_{electric})\,. \qquad (2)$$

In real technological devices, this dependence has the form:

$$P_{acoustic} = (0,4 \div 0,48) P_{electric} \qquad (3)$$

The method of stabilizing the shift amplitude of the sonotrode working end realized in technological ultrasonic plants has successfully passed tests at the “RUSAL ITC” Co. (aluminum melts) and at the FGUP scientific-productional centre of gas turbine construction «Salyut» (to strengthen the turbine blades).

V. Effectiveness Study Of Aluminium Melt Treatment

Effectiveness study of designed equipment was conducted in experimental-industrial conditions at RUSAL Co. site. Test output was semi-continuous casting of large ingots of aluminum alloy 5052. The influence of the cavitation effect on grinding of iron-containing constituents and Mg2Si phases was determined. The alloy's chemical composition is given in table. 1.

Table 1

Alloy 5052 chemical composition

Alloy grade	Constituents , %							
	Mg	Fe	Si	Cr	Ti	B	Mn	Al
5052	2,37	0,24	0,12	0,18	0,017	0,0006	0,012	basis metal

Casting was carried out in water-cooled molds of 600 x 1630 mm cross-section by standard technology. Ultrasonic treatment was carried out in the melt flow up to the crystallization at 700-720 °C and 17.4 kHz, 1.5 or 3.0 kW. Ingots structure was studied on etched sections. Results of the study are presented in table. 2 and Fig. 5.

Table 2

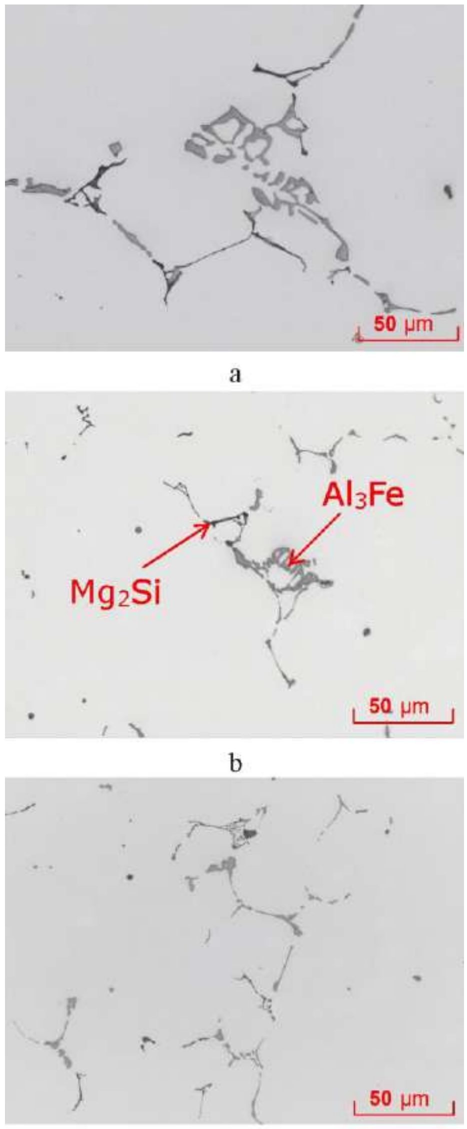
Effect of melt processing technology on the phase structure of Al3Fe and Mg2Si

Melt processing technology	**Quantitative characteristics of phases**			
	Linear phase size, D_{cp}, µm (D_{min}-D_{max})		**Volume fraction of phases in the structure, %**	
	Al_3Fe	**Mg_2Si**	**Al_3Fe**	**Mg_2Si**
no UST (residual-current device)	40,6 (12,9-78,9)	35,1 (12,9-77,4)	2,0	0,38
1,5 kW UST	36,0 (12,6-70,8)	28,8 (14,9-70,1)	1,9	0,30
3 kW UST	31,1 (13,2-62,1)	30,8 (17,6-48,7)	2,3	0,33

Volume fraction of phases in microstructure does not differ significantly from processing technology, whereas their linear dimensions have a number of significant differences. So, average phase size of Al3Fe due to ultrasonic treatment is reduced by 25%, and Mg2Si by 10%. And such a grinding of the average size occurs as a result of a significant reduction in the number of phases is larger than 50 - 60 µm. Maximum phase value of Al3Fe is crushed from 79 to 62 µm, and Mg2Si from 77 to 49 µm, i.e. the more power and ultrasound amplitude, the better cavitation effect on the melt flow during casting of large aluminum alloy ingots.

VI. Conclusions

Device for ultrasonic treatment of aluminum and magnesium alloys, developed by the "RELTEC" company, can be easily adapted for existing or developing lines, which are designed for preparation of, aluminum and magnesium melts and casting technologies, for high-quality products with increased resource characteristics. The high efficiency of the technological process of degassing or doping the melt with nanodispersed intermetallic materials is achieved by the controllability of the ultrasonic treatment with a constant control of the energy transferred to the melt and the oscillations of the immersed radiating sonotrode A significant reduction in the time of ultrasonic treatment of the metal melt makes this method most economically viable and environmentally friendly.



c

Fig. 5. Phases structure (Al3Fe and Mg2Si) no UST (a) и UST (b, c): 1,5 kW – b, 3,0 kW – c.

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